Narrow waveband sensor for continuous canopy NDVI, PRI, and NWI measurement

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Introduction

As concerns over rising atmospheric carbon dioxide (CO_2) levels continue, it is critical to understand the mechanisms of mass and energy balance between the atmosphere and the biosphere for monitoring current and estimating future fluxes. Networks of environmental monitoring sensors are increasingly being used to continuously collect data important to understanding the interaction between plant canopies and the atmosphere. While spectral data are critical to scaling CO_2 flux estimates, the number of flux towers currently equipped with continuous spectral data collection are few with high purchasing and maintenance costs of hyperspectral spectroradiometers being the primary limiting factors (Gamon et al., 2006; Garrity et al., 2010). A low-cost, low-maintenance, high data-quality option is needed to outfit a significant number of flux tower locations with continuous spectral measurements.

Building on a simple photodiode sensor (QuadPod) designed by Garrity et al. (2010) to continuously collect NDVI (675 and 800 nm) and PRI (532 and 570 nm) data, we added a spectral index related to plant water status (880 and 970 nm) to our Triple Vegetation Index Radiometer (TVIR).

Instrument Description

Figure 1. Triple Vegetation Index Radiometer (TVIR). From left, sensor configured to capture downwelling radiation (irradiance), combined sensor prototype, and sensor configured capture upwelling radiation (radiance).

- Commercially available components
- Custom housing
- Dual sensor: irradiance + radiance
- 20˚ field of view on radiance sensor
- CR10x Campbell Scientific integration
- 3.5 mm RCA cables

Photodiodes and bandpass filters

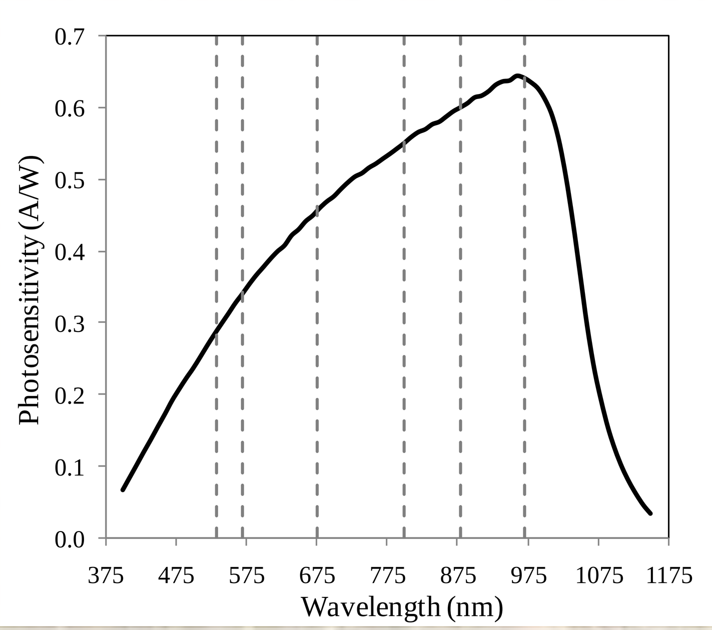

Figure 2. Photosensitivity response curve for the silicon diode used in the TVIR (data from Pacific Silicon Sensor, Inc.). The wavelengths used to calculate NDVI, PRI, and NWI-3 are represented by vertical dashed lines (532 nm, 570 nm, 675 nm, 800 nm, 880 nm, and 970 nm).

Photodiodes and bandpass filters (con't)

- Photodiodes with narrow bandpass filters : Model T-18, Intor, Inc.
- Photodiodes in series with a 2000 ohm shunt resistor
- Voltage measured by 24 bit analog to digital (A to D) converter with built-in multiplexer / preamplifier
- Data read by microcontroller with 1s sampling interval
- Data output as a SDI-12 serial stream
- Photodiodes in flat-top cylindrical virgin PTFE diffusers positioned 1 mm above the instrument housing. This provided lowest mean cosine response error, lowest bias, and least root mean squared deviation from expected irradiance (data not shown).

Photodiode/bandpass filter confirmation

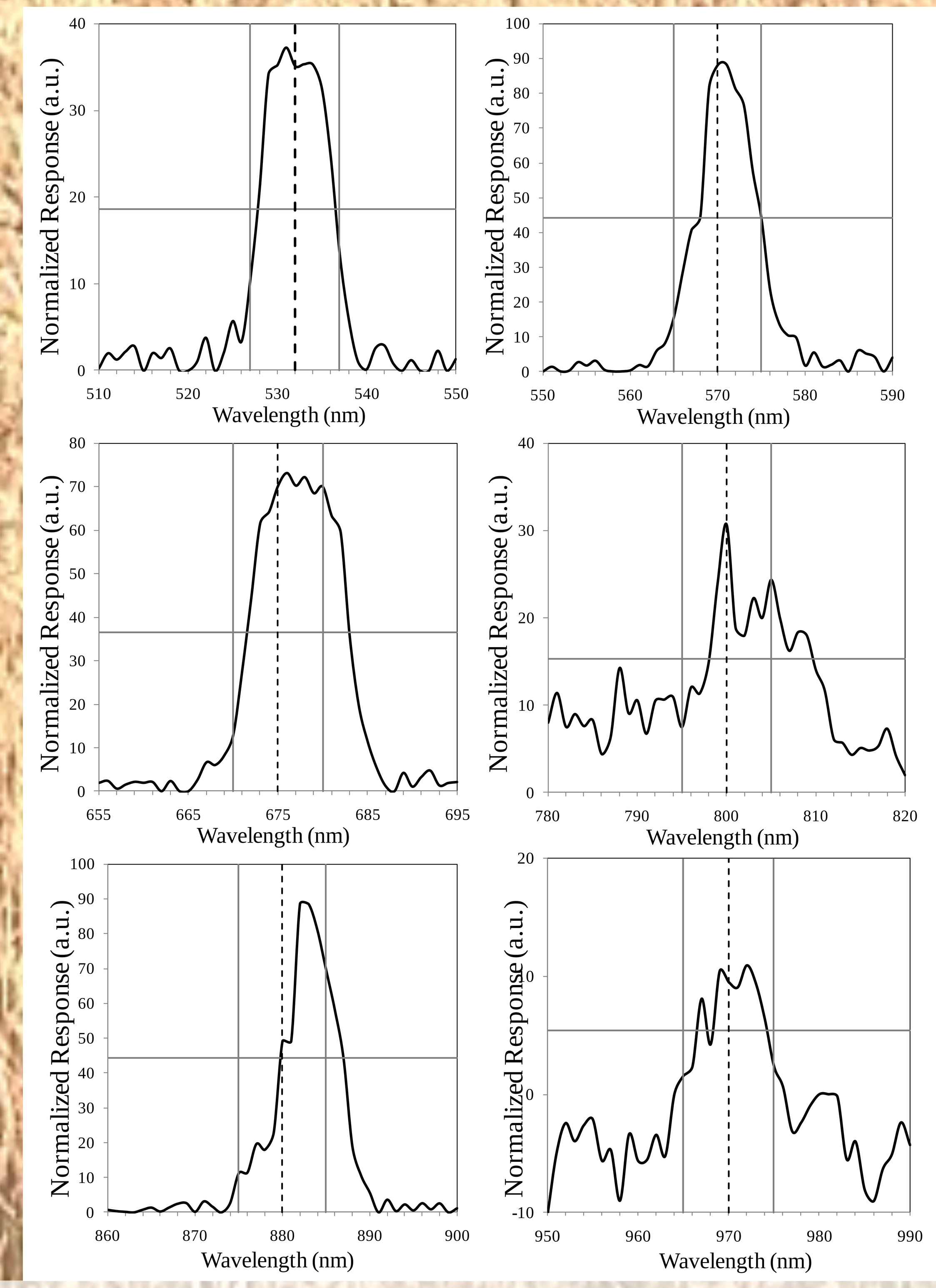

Figure 3. Photodiode response using six narrow bandpass filters. Data were generated using a tunable ellipsometer set to 1 nm sampling intervals as a light source. Gray and dashed lines represent the full width half maximum and peak transmission of the bandpass filters (as reported by the manufacturer), respectively.

TVIR repeatability and response to ground cover

- Data collected continuously for 120 s at 5 s sampling intervals
- Data then grouped into continuous 30 s segments
- Mean standard deviation for all groups was 30.9 digital numbers (DN)
- Represents 0.0002% of the total signal (16777216 DN) at max output

Table 1. Average spot measurements of NDVI, PRI, and NWI-3 for grass in full sun, shaded grass, and bare soil in full sun.

	Grass (sun)	Grass (shaded)	Bare Soil (sun)
NDVI	0.46 (0.03)	0.46 (0.14)	0.08 (0.06)
PRI	0.12 (0.03)	0.10 (0.18)	0.06 (0.04)
NWI3	-0.01 (0.02)	-0.05 (0.13)	0.07 (0.05)

Stadard deviation in parenthesis; 120 second measurements

TVIR comparison with Unispec DC

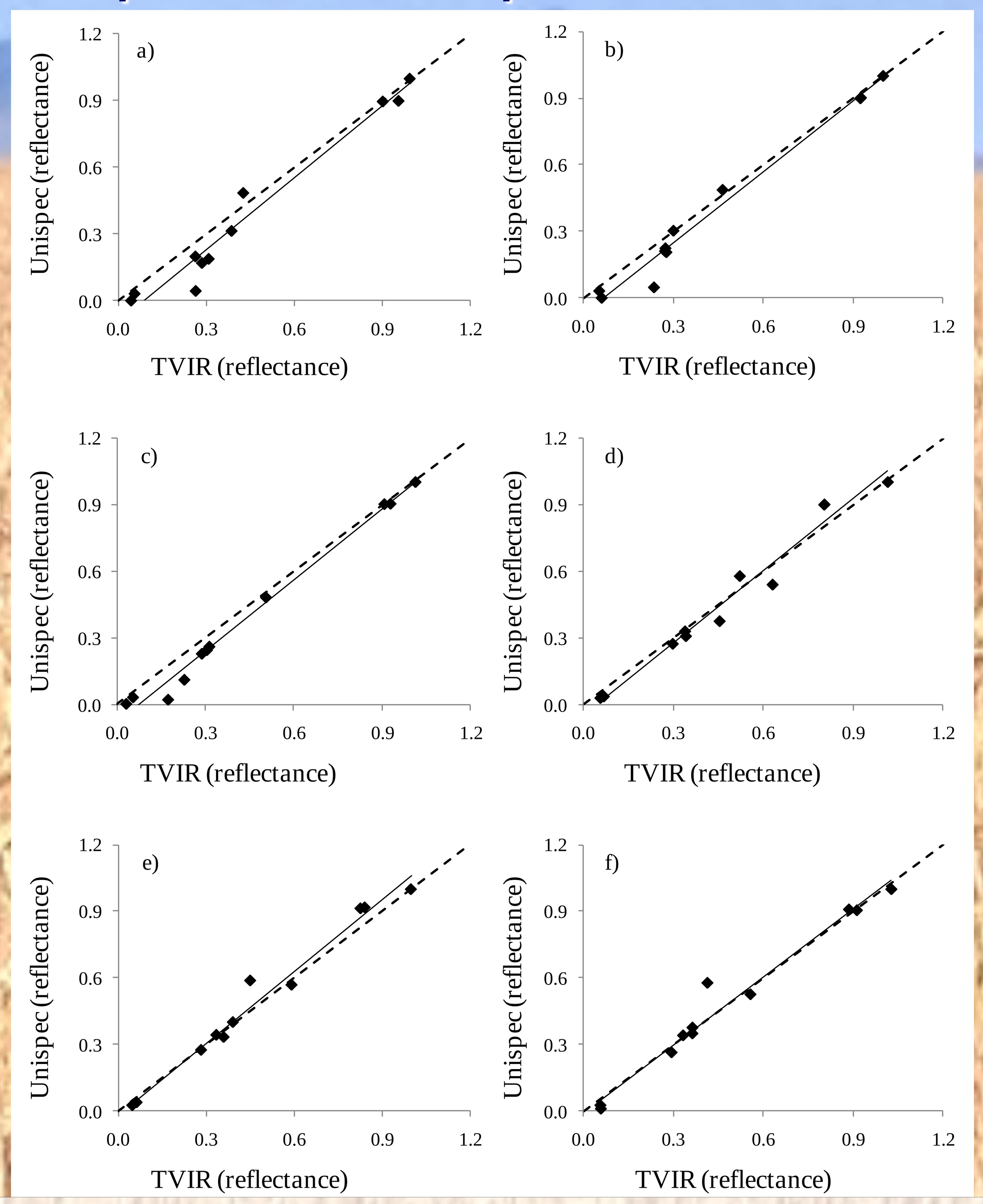

Figure 4. Regression of TVIR radiometer reflectance on UniSpec DC reflectance at a) 532 nm, b) 570 nm, c) 675 nm, d) 800 nm, e) 880 nm, and f) 970 nm.

Table 2. Good of fit statistics comparing TVIR and Unispec DC reflectance.

Wavelength	RMSD	Bias	SB†	NU†	LC†	R^2
532 nm	0.093	0.060	41.2	15.4	43.4	0.97
570 nm	0.068	0.043	39.1	14.6	46.3	0.98
675 nm	0.068	0.053	59.0	13.8	27.2	0.99
800 nm	0.061	0.008	1.7	31.3	67.0	0.97
880 nm	0.056	-0.019	11.6	28.5	59.9	0.98
970 nm	0.056	-0.001	0.1	6.6	93.3	0.97

RMSD = root mean squared deviation, SB = squared bias, NU = non-unity, LC = lack of correlation
† percent of mean squared deviation (MSD)

Conclusions

- Initial testing suggests the TVIR is capable of providing high quality, high temporal resolution canopy reflectance data.
- TVIR wavebands compared well to similar UniSpec DC wavebands ($R^2 > 0.97$, low RMSD).
- Short-term repeatability of the TVIR 0.0002% of the total signal.
- Insensitive to shading; responsive to reflectance from differing ground covers.
- Further calibration could reduce 532 nm, 570 nm, and 675 nm bias.
- Longer fixed integration time of the UniSpec likely the cause of the deviation from 1:1
- Future testing: long-term repeatability/stability and temperature sensitivity in field conditions.

References

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Garrity, S.R., L.A. Vierling, and K. Bickford. 2010. A simple filtered photodiode instrument for continuous measurement of narrowband NDVI and PRI over vegetated canopies. Agricultural and Forest Meteorology. 150:489-496.

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